Claims

1. (~~Previously presented~~ currently amended) A mixed-mode fuel injector comprising:

(i) a nozzle body (5) including a tip (7), comprising passages for fuel (FP)~~,~~ which includes an inner cylindrical space for receiving a needle valve (1), and an inner conical surface (C) ~~close to~~at the tip (7) of the nozzle body, the conical surface (C) ~~for~~ guiding a spray of fuel;

(ii) a needle valve (1), which has a converging-diverging conical head wherein the head diverges at its upstream end and converges at its downstream most end for guiding a spray of fuel, the needle valve including a conical seal surface (2) upstream of the head; ~~and which is~~ wherein the needle valve being ~~-~~movable ~~back and forth~~ between open and closed positions by a driving means within the ~~and received in said~~ nozzle body, wherein ~~said~~ the needle valve is at a biased close~~d~~~~ing~~ position with its seal surface (2) being pressed against nozzle body (5) to block fuel flow, or in an opening position ~~defined by driving means through lifting~~ the ~~said~~ needle valve seal surface being lifted away from nozzle body to permit fuel flow; and

(iii) a micro-variable-circular-orifice comprising a variable annular ring aperture (4) between ~~said~~ the needle valve and ~~said~~ the nozzle body ~~which has means of~~ for producing a hollow conical spray, and ~~at least one~~between 1 and 20 conventional multijet-orifices (6) ~~inside~~ distributed underneath the conical surface (C) as closed channels each for ~~the said nozzle body (5) which has means of~~ producing ~~at least~~ one conventional jet spray, such that fuel is dischargeable in variable sprays of hollow conical and multiple jets ~~shapes~~ through said micro-variable-circular-orifice and multijet-orifices by lifting said needle valve ~~at different magnitudes~~ to different positions, with hollow conical spray pattern being produced first followed by multiple jet spray patterns.

2. (~~Previously presented~~ currently amended) ~~A mixed-mode fuel injector according claim 1, wherein the micro-variable-circular-orifice further comprises a plurality of multijet-orifices (6).~~ A mixed-mode fuel injector comprising:

(i) a nozzle body (5) including a tip, comprising a passage for fuel (FP) which includes an inner cylindrical space for receiving a needle valve (1), and an inner conical surface (C) at the tip (7) of the nozzle body, the conical surface guiding a spray of fuel;

(ii) the needle valve (1) having a converging-diverging conical head wherein the head diverges at its upstream end and converges at its downstream most end for guiding a spray of fuel, the needle valve including a conical seal surface upstream of the head; wherein the needle valve being moveable between open and closed positions by a driving means within the nozzle body, wherein in the closed position the sealing surface of the needle valve is pressed against nozzle body (5) to block fuel flow, and in the open position the needle valve seal surface being lifted away from nozzle body to permit fuel flow, and

(iii) a micro-variable-circular-orifice comprising a variable annular ring aperture (4) between the needle valve and the nozzle body for producing a hollow conical spray, and between 1 and 20 multijet-orifice (6) distributed on the conical surface (C) as open channels each for producing a jet spray, such that fuel is discharged in variable spray patterns of hollow conical and multiple jets through the micro-variable-circular-orifice by lifting the needle valve to different positions, wherein the maximum needle lift for the opening position is in the range of 1-300 micrometers, the needle head diameter at its widest portion is in the range of 0.8-3.5mm, and the angle between a centerline of the nozzle body (5) and the inner conical surface (C) at the nozzle body tip (7) is approximately in the range of 35-75 degree.

3. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim 1 ~~or 2~~, wherein the conical surface (C) has a single conical surface.

4. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim 1 ~~or 2~~, wherein the conical surface (C) is an integrated conical surface having two or more conical surfaces with different conical angles connected together.

5. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim 1 ~~or 2~~, wherein the conical surface (C) is a diverging curved surface.

6. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim 1 ~~or 2~~, wherein the needle lift for the opening position is approximately in the range of 0-300μm, the needle head diameter is approximately in the range of 0.8-3.5mm, and the angle between the centerline of the nozzle body (5) and the inner conical surface (C) at the nozzle body tip (7) is approximately in the range of 35-75 degree.

7. (Previously presented) A mixed-mode fuel injector according to claim 2, wherein the plurality of multijet-orifices (6) is on the said conical surface (C) with cross sections that are one or more of semi-circles, arcs, triangles, trapezoids or other polygons.

8. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim ~~2~~ 1, wherein the needle head (3) remains at least partially received within the tip (7) as the needle valve (1) is moved back and forth between the biased closing position and opening position such that when fuel is injected through the micro variable aperture (4) between the needle head and said conical surface of the nozzle body, fuel is also injected through the multijet-orifices *(6)*, the upper surface of the needle head and the conical surface serve as guiding surfaces for fuel sprays.

9. (Previously presented) A mixed-mode fuel injector according to claim 7, wherein there are about 4-20 multijet-orifices with the cross-section of semi-circles with the diameters approximately in the range of 50-300μm.

10. (Previously presented) A mixed-mode fuel injector according to claim 7, wherein there are about 4-20 multijet-orifices (6) having a cross-section other than semi-circles with the maximum dimension approximately between 50-400μm.

11. (Currently amended) A mixed-mode fuel injector according to ~~any of *claims 2 to 10*~~ *claim 1*, wherein the sizes of said multijet-orifices (6) are the same.

12. (Currently amended) A mixed-mode fuel injector according to ~~any of *claims 2 to 10*~~ *claim 1*, wherein the sizes of the multijet-orifices (6) are different depending on specific needs of atomization.

13. (Cancelled)

14. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim ~~2~~ 1, has a plurality of multijet-orifices underneath the said conical surface (C), forming a sac-hole or valve-covered-orifice multi-hole type injector through blocking the circular aperture by the needle head at a predefined needle-lift range.

15. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim ~~2~~ 1, wherein different shapes of fuel sprays are generated by changing the magnitude of lift of said needle valve (1) and the needle valve is arranged within the nozzle body (5) so that, at low to medium injection loads, fuel is mainly injected through the variable circular aperture between the needle head (3) and conical surface (C) of nozzle body (5) by a small needle lift, thus mainly forms a conical shape spray, while at high injection loads, fuel is injected through both the variable circular aperture between the needle head and nozzle body and the multijet-orifices (6) by a larger needle lift, thus forms a mixed-mode conical-multi-jet shape spray, whereby provides different atomization desired by engine combustion at different loads.

16. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim ~~2~~1, wherein different shapes of fuel sprays are generated by changing the magnitude of lift of said needle valve (1) and the needle valve is arranged within the nozzle body (5) so that, at low to medium injection loads, fuel is mainly injected through the variable circular aperture between the

needle head (3) and conical surface (C) of nozzle body by a small needle lift, thus mainly forms a conical shape spray, while at high injection loads, the needle head can completely or partially block the variable circular aperture by a large needle lift, whereby fuel is fully or mainly injected through the multijet-orifices (6), which can be open channels or closed channels depending on penetration needs, thus mainly forms conventional multi-jet sprays at high loads, whereby provides different penetration desired by engine combustion at different loads.

17. (Cancelled)

18. (~~Previously presented~~ currently amended) A mixed-mode fuel injector according to claim 1 ~~or 2~~, wherein the angle between the centerline of the conical surface (C) and the centerline of the nozzle body (5) is approximately 0-15 degrees, depending on an angle between a centerline of the fuel injector and a centerline of a piston in an engine cylinder.

19. (Cancelled)
20. (Cancelled)

21. (Cancelled)
22. (Cancelled)
23. (Cancelled)

## Remarks

Claims were rearranged into 2 independent claims 1 & 2, with claim 1 being dedicated to a variable orifice fuel injector with a circular ring aperture (4) and closed channels (6) underneath the nozzle tip conical surface (C), and claim 2 being dedicated to a variable orifice fuel injector with a circular ring aperture and open channels on the nozzle tip conical surface (C). Revisions of claim 1 & 2 have incorporated the examiner's interview comments on June 7th, 2011.

Revision of claim 1 shall overcome the Date Reference, JP10-299613. The Date Reference does not has the conical surface (C) at nozzle tip as the 10/597000 application does, at the same time, the Date Reference has a cylinder part 33 while the 10/597000 application does not. These fundamental differences make two distinctive injectors with distinctive spray pattern sequences, as discussed in previous response dated May 22nd, 2011.

The revised claim 1 shall also overcome the Simmons Reference, U.S. Patent #3,042,317, since the Simmons Reference simply does not have multijet channels, it does not produce jets with variable spray patterns.

Claims 3-6, 8, 11-12, 14-16, 18 were revised to become single dependent claims of claim 1;

Claims 13, 17, 19-23 were cancelled.

No new matter is added, rather than rearrange the contents previously presented.

Respectfully submitted,

/Deyang Hou/
June 26th, 2011
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